Absorption Cross Section of Helium and Argon in the Extreme Ultraviolet

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The absorption of radiation of wavelength between 240 A and 1000 A in helium and argon was measured photometrically in a grazing incidence vacuum spectrograph. For helium a sharp absorption edge was observed at 504.3 A. Near this edge the photoionization cross section at 495.7 A was found to be 6.95×10^{-18} cm². The variation of the cross section as a function of the wavelength was in agreement with the computed curves by Wheeler and Vinti within the experimental error limit. For argon three absorption edges exist at 786.8 A, 778.0 A, and 424.0 A corresponding to the M_3, M_2, and M_1 edges, respectively. Possible auto-ionization phenomena between the M_2 and M_3 edges were observed. The cross section at the M_2 edge was found to be 3.5×10^{-17} cm² which is comparable with the value computed by Dalgarno.

INTRODUCTION

THE absorption of radiation in the extreme ultraviolet by inert gases was first observed qualitatively by C. Cuthbertson.[1] During the recent years photometric techniques in the vacuum ultraviolet have been improved to such an extent that the determination of absorption cross sections of gases in this spectral region was possible within an experimental error of about ten percent. The cross sections of neon[2] have been measured and were found to be in good agreement with the values computed by Seaton. This work concerns itself with the cross sections of helium and argon. Results were obtained in the same manner as described for neon.[2] Tank helium and argon were supplied by the Air Reduction Pacific Company, Los Angeles, California. The helium contained 1×10^{-4} parts of hydrogen, and argon 10^{-3} parts of oxygen as impurities, fractions too small to introduce serious experimental errors.

The determination of the absorption coefficient was based on Beer's law,

$$I=I_0e^{-kx},$$

where the absorption coefficient, k, is in units of cm^{-1} at N.T.P. The cross section σ is given by

$$\sigma=k/N,$$

where N is Loschmidt's number. In the foregoing equations, I_0 and I are the incident and emergent intensities of light when passing through a layer of the absorbing gas x cm thick at N.T.P. From the photometric determination of the emergent intensities at different pressures of the absorbing gas, the k-values were thus obtained.

TABLE I. Absorption coefficients in helium as a function of the wavelength.

Source line wavelength (A)	k (cm^{-1})	Source line wavelength (A)	k (cm^{-1})
OIV 779.8	0	2× NII 418.9	120
OII 675.7	0	2× OIII 395.6	92
NII 635.1	0	2× OIII 374.0	95
HeI 584.3	75	2×NIII 362.9	84
NII 506.1	0	2×NIII 358.3	98
? 495.7	186	2× OIII 328.1	75
OII 485.6	162	2×NIII 323.6	80
? 452.0	160	2× OIII 306.0	45
2×OIII 445.6	142	2× NIV 283.6	30
2× OII 434.9	115	2× NIV 247.2	25
2× NII 428.2	110	2× OIV 239.6	25

PHOTOIONIZATION CROSS SECTIONS IN HELIUM

Helium is transparent in the wavelength region longer than 504.8 A except for resonance line absorption.

Many source lines near 500 A were available for this investigation, since a mixture of argon and helium was used as a discharge carrier gas in the light source.[3]

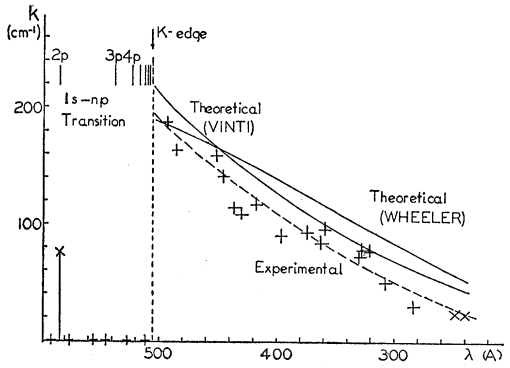

FIG. 1. Absorption coefficients of helium as a function of wavelength. + represents the measured values of the coefficient k and × indicates values whose error limit is larger than 15 cm^{-1} but unknown. The solid curves indicate the absorption contour computed by Vinti and by Wheeler.

A sharp absorbing edge was observed between the source lines AII 504.80 and AII 503.64 which agreed with the computed value 504.27 A from spectroscopic data.[4] The k-values of the adjacent continuum are given in Table I and shown in Fig. 1. The absorption of HeI 584.3, a resonance line of helium, was due to a process of photoexcitation. The continuous absorption

[1] C. Cuthbertson, Proc. Roy. Soc. (London) **A114**, 650 (1927).
[2] Po Lee and G. L. Weissler, Proc. Roy. Soc. (London) **A219**, 71 (1953).
[3] Po Lee and G. L. Weissler, J. Opt. Soc. Am. **42**, 80 (1952).
[4] C. E. Moore, *Atomic Energy Levels*, National Bureau of Standards, Circular No. 467 (U. S. Government Printing Office, Washington, D. C., 1949), Vol. I, p. 4.

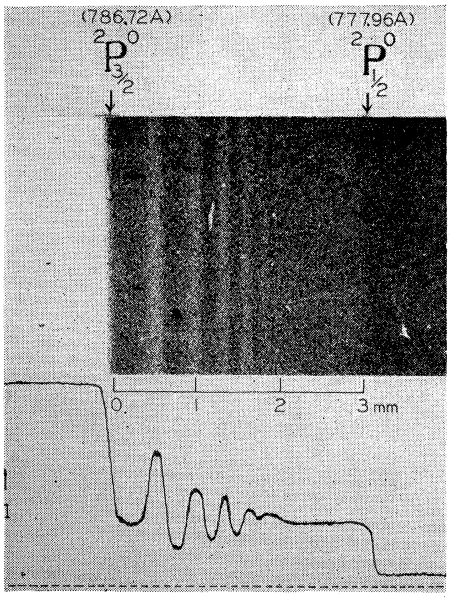

FIG. 2. A photograph of the absorption spectrum of argon between the M_3 and M_2 edges. The lower curve is the corresponding microdensitometer trace.

was obviously due to photoionization in which a 1*s*-electron in the ground state was ejected from the atom by the incident photon. Wheeler[5] and Vinti[6] have computed the absorption coefficient of helium. Their results are shown in the Fig. 1 as solid lines. The theoretical cross section obtained at the spectral head was 7.4×10^{-18} cm^2, while the experimental value from the extrapolation of the dashed curve in Fig. 1 was 7.3×10^{-18}. The experimental cross sections fall off more rapidly than Wheeler's and seem to follow Vinti's curve more closely, with a probable error in the measurements of about 15 cm^{-1}.

PHOTOIONIZATION CROSS SECTIONS OF ARGON

Since argon has a lower ionization potential than helium, its absorption extended over a comparatively

TABLE II. Absorption coefficients in argon as a function of the wavelength.

Source line wavelength (A)	k (cm^{-1})	Source line wavelength (A)	k (cm^{-1})
AIV 843.7	0	AII 725.5	880
AIV 827.3	0	AIV 700.3	950
? 781.2	520	AIV 683.2	940
OIV 779.8	515	NII 671.7	940
NII 776.0	960	NII 660.3	900
NIII 772.3	920	OII 644.1	900
NIII 771.9	970	AIII 637.2	900
AIII 769.1	890	OIV 625.8	860
NII 747.0	940	OII 617.1	850
NII 745.8	940	AII 602.8	850

[5] J. A. Wheeler, Phys. Rev. **43**, 258 (1933).
[6] J. P. Vinti, Phys. Rev. **44**, 524 (1933).

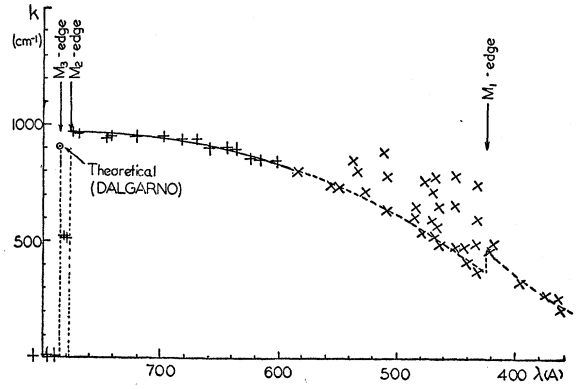

FIG. 3. Absorption coefficients of argon as a function of wavelength. + represents the measured values of the coefficient k and × indicates values whose error limit is larger than 50 cm^{-1} but unknown. ⊙ indicates the value computed by Dalgarno.

larger spectral region. The continuous emission spectrum of molecular helium[7] served in this case as a light source to provide qualitative information on the absorption of argon near its ionization limits. The spectrum thus obtained showed two sharp absorption edges near 786 A. There was a group of resonance absorption lines at longer wavelengths due to $3p\rightarrow nd$ and $3p\rightarrow ms$ transitions. Like helium and neon, the absorption coefficients in these resonance lines were smaller than those in the continuous absorption and are not given here. The print in Fig. 2 shows the absorption spectrum between the edges at 786.72 A and at 777.96 A, respectively. Below the print is the corresponding microdensitometer trace. A series of resonance lines which converged to the M_2 edge as a limit is in evidence. They are diffuse due to the perturbation of the adjacent

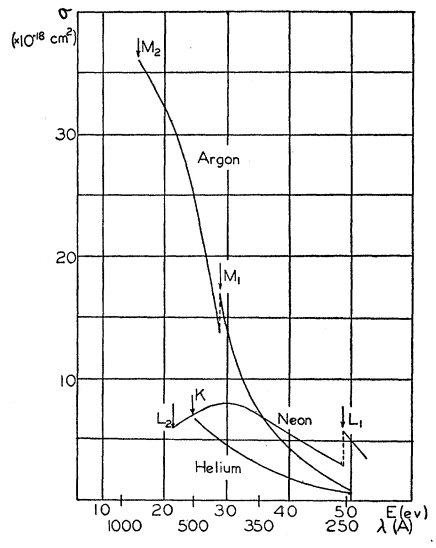

FIG. 4. Absorption cross sections of the three inert gases, argon, neon, and helium.

[7] Y. Tanaka, Sci. Papers Inst. Phys. Chem. Research (Tokyo) **39**, 465 (1942).

continuum of the $^2P_{\frac{3}{2}}^\circ$ ionization limit. It is therefore not surprising that the cross sections were found to vary rapidly in this region.

The absorption coefficients of argon were measured with a discrete line emission source in the same manner as neon and helium and results are presented in Table II and Fig. 3 with a probable error of about 50 cm^{-1}.

Near the M_3 edge, the first ionization limit, two low k-values were obtained for source lines ? 781.2 A and OIV 779.8 A. They might be considered as indicative of the magnitude of the photoionization cross section due to the transition of one of the $3p$-electrons to the continuous level corresponding to the series limit $^2P_{\frac{3}{2}}^\circ$. Below the M_2 edge the measured k-value represents the total contribution of two possible transitions and falls off slowly toward shorter wavelengths At the M_2 edge the cross section was estimated to be 3.5×10^{-17} cm^2. This may be compared with the photoionization cross section of 3×10^{-17} cm^2 as calculated by Dalgarno[8] for argon at the spectral head.

In the range between 550 A and 420 A, many comparatively large k-values were found as indicated by crosses above the dashed curve in Fig. 3. They may possibly be explained as due to autoionization near the M_1 edge. In contrast, below this edge the absorption coefficients were found uniformly lower.

In summarizing the results obtained, the variation of the photoionization cross sections of helium, argon, and neon *versus* the energy of the incident photon are shown in Fig. 4.

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[8] A. Dalgarno, Proc. Phys. Soc. (London) **A65**, 666 (1952).

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Photoionization Efficiencies and Cross Sections in O_2, N_2, CO_2, A, H_2O, H_2, and CH_4

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The photoionization cross sections of several gases were obtained by making simultaneous measurements of the total absorption cross sections and ionization efficiencies in the wavelength region from 473 A to 1100 A. In each case the total absorption cross sections were in agreement with those reported by others. For O_2, the ionization cross sections were found to be between 5 and 30×10^{-18} cm^2, while those for N_2 were close to 23×10^{-18} cm^2 over almost the entire range studied. The ionization cross section of argon at the onset of ionization was compared with the theoretical estimate made by Dalgarno. The long-wavelength limits for photoionization were determined and were found to yield ionization potentials in good agreement with those obtained by spectroscopic and electron impact methods.

INTRODUCTION

PRESENT interest in the physics of the upper atmosphere and in that of gaseous discharges has motivated a renewed effort to measure the photoionization cross sections of several of the permanent gases. For a few gases, such as Ne,[1] A, CH_4,[2] and the alkali metal vapors,[3] these cross sections may be inferred from their total absorption cross sections. However, since in many gases several competing absorption processes may be expected, the most unambiguous results can be obtained only from a direct measurement of the number of ion pairs produced per photon absorbed in the gas.[4,5]

The work reported here was concerned with measurements of the absolute photoionization cross sections and ionization efficiencies of O_2, N_2, CO_2, A, H_2, H_2O, and CH_4 as a function of wavelength between 473 and 1020 A. Techniques employed in this investigation were essentially the same as those described in an earlier paper containing preliminary results for O_2 and N_2.[6]

APPARATUS AND PROCEDURE

The equipment employed in this study consisted of three major components, a light source and normal-incidence vacuum monochromator, instruments for determining the absolute light intensity at the exit slit, and an assembly of ion chambers, mounted in a gas-filled experiment chamber behind the exit slit, in which the ionization currents and absorption coefficients were measured. The light source and monochromator have been described previously.[6] A line-emitting light source was used in preference to the frequently employed continuum in order to facilitate the separation of first-

[1] P. Lee and G. L. Weissler, Proc. Roy. Soc. (London) **A219**, 71 (1953).
[2] H. Sun and G. L. Weissler, J. Chem. Phys. (to be published).
[3] Ditchburn, Tunstead, and Yates, Proc. Roy. Soc. (London) **A181**, 386–99 (1943).
[4] F. L. Mohler, Phys. Rev. **28**, 46–56 (1926).
[5] Watanabe, Zelikoff, and Inn, AFCRC Technical Report No. 52–53 (unpublished); also, Phys. Rev. **91**, 1155 (1953); K. Watanabe, J. Chem. Phys. **22**, 1564 (1954).
[6] Wainfan, Walker, and Weissler, J. Appl. Phys. **24**, 1318 (1953).

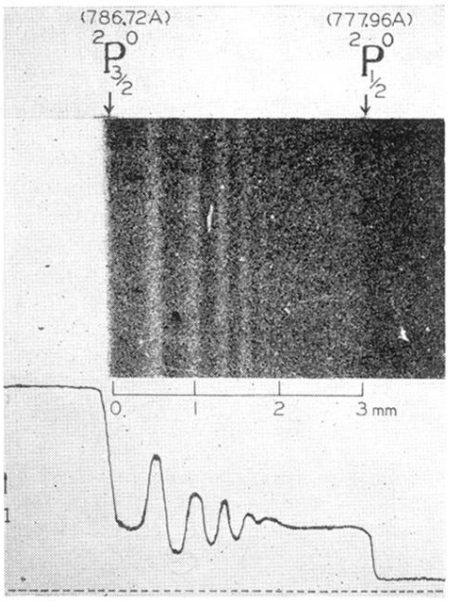

FIG. 2. A photograph of the absorption spectrum of argon between the M_3 and M_2 edges. The lower curve is the corresponding microdensitometer trace.